LEVEL II

November 12, 1981

TO: Mr. Lee Webster, ATC-T
Project Engineer
Ballistic Missile Defence
Advanced Technology Center
P.O. Box 1500
Huntsville, AL 35807

FROM: Professor Robert D. Hunsucker

SUBJECT: Final Report, Title: Ionosphere Research
Contract No. DASG60-80-C-0047

Objectives:

The aim of the contract between BMC/ATC and the Geophysical Institute of the University of Alaska (GI/UAF) has been to provide support for Mr. Robert Freyman of Los Alamos National Laboratories (LANL) to conduct investigations of the long-delay-echo (LDE) phenomenon at field sites in the auroral zone.

Personnel:

The Principal Investigators of the project were Professor Robert Hunsucker of the GI/UAF and Mr. Robert Freyman of LANL, with Professor Syun-Ichi Akasofu of the GI/UAF as a participating scientist. Mr. Brett Delana was project engineer, Miss Kay Driscoll worked as electronic technician and Ms. Pat Brooks (all of GI/UAF) was project administrator. Mr. Al Koelle of LANL assisted Mr. Freyman as electronic engineer. Mr. Lee Webster of BMD/ATC was the sponsor project engineer.

The first visit to the GI/UAF to consider the feasibility of the LDE study was conducted by Mr. Larry Atha, Dr. Darell Harman, Mr. Lee Webster and Mr. Robert Freyman during the period 10-11 July 1979.

Tasks Accomplished:

In general, extensive field site and equipment modifications were accomplished by the project staff and assistance was provided to Mr. Freyman and Mr. Koelle during three operating campaigns:

1. 8-22 July 1980
2. 18-26 September 1980
3. 23 June-8 August 1981

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LDE's were, in fact, observed by Mr. Freyman during campaigns and reported in two publications,

a. "Measurements of long delayed radio echoes in the auroral zone," R. W. Freyman, Geophysical Research Letters, Vol. 8, No. 4, pages 385-388, April, 1981.

b. (This report has not yet been released for publication by LANL).

More specifically, as reported in our Progress Reports No. 1 (June 11, 1980) and No. 2 (January 22, 1981) our GI/UAF staff:

a. Refurbished a U.S. Navy surplus 4 KW HF transmitter to accommodate the emissions required by Mr. Freyman (about 3 man weeks). The transmitter was tuned to operate on 9.9, 14.5 and 15.4 MHz.

b. Modified the already existing electronic antenna switching panel to change from an ionosonde send/receive mode to a circularly polarized configuration for the LDE study.

c. Installed and erected an antenna and assisted in assembling equipment at Ballaine Lake field site.

d. Assisted Mssrs. Freyman and Koelle in a complete and thorough test of system frequency stability, spectral purity, etc.

e. Assisted LANL personnel in all areas of logistics associated with their campaigns, i.e., transportation, housing, reservations, shipping and receiving of equipment, etc.

f. Installed a telephone at the Sheep Creek site to facilitate communication.

In addition, extensive discussions on theoretical and experimental relations were held between Professors Akasofu and Hunsucker and Mr. Freyman.

Campaigns:

1. 15-22 July 1980 - over 2000 LDE's detected at 9.9 MHz. A positive correlation was obtained between the number of reflections per unit time and local disturbed magnetic conditions.

2. 18-26 September 1980 - no LDE's detected. Lack of success in observing LDE's partially attributed to the extremely high level of propagated HF interference received at College near the 9.9 MHz operating frequency during this part of the sunspot cycle. Tried two different field sites in the College area.

3. 23 June-8 August 1981 - many LDE's detected. The official LANL report has not yet been released. Mr. Freyman indicated that the reception pattern of the LDE's indicated that they were propagating in ducts tens of meters in diameter and kilometers in separation.

During the period 3-8 August 1981, our staff assisted Mssrs. Freyman and Koelle in disassembling the LDE equipment at the Sheep Creek field site and restoring the site to its original condition.

RDH:pb

cc: ATC-M - 5
ATC-R - 1
DACS-BMT - 1
BMDSC-AOLIB - 1
DTIC - 2
R. Freyman - 1
GI/UAF Internal - 6

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MEASUREMENTS OF LONG DELAYED RADIO ECHOES IN THE AURORAL ZONE

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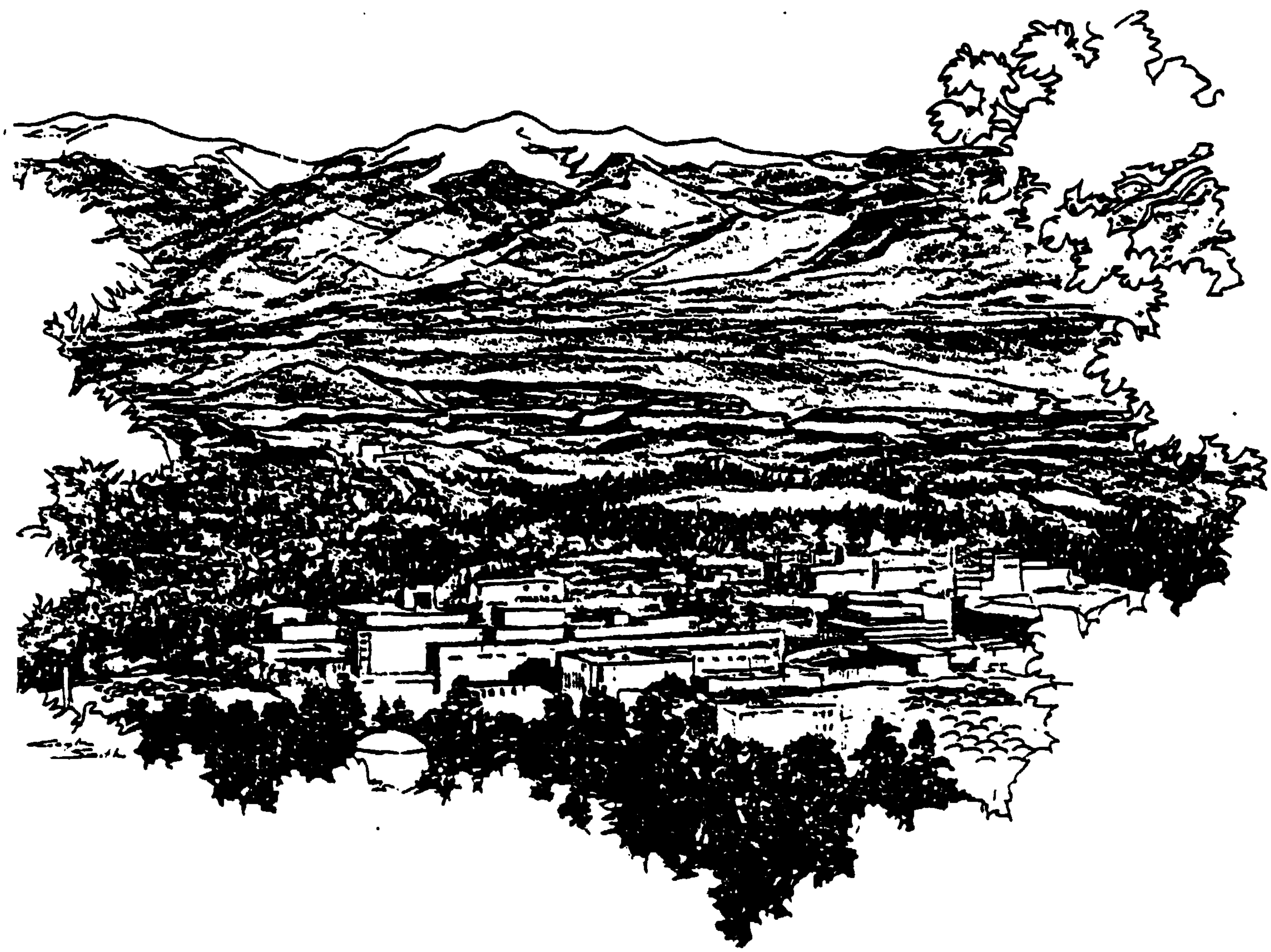

LOS ALAMOS NATIONAL LABORATORY

GEOPHYSICAL RESEARCH LETTERS, VOL. 8, NO. 4, PAGES 385-388, APRIL 1981

MEASUREMENTS OF LONG DELAYED RADIO ECHOES IN THE AURORAL ZONE

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Abstract. A high-latitude, earth-based high-frequency (9.9MHz) radiowave backscatter technique for the real-time detection of Long Delayed Echoes was tested at College, Alaska. Over 2000 apparent LDE were detected and recorded from 15 to 22 July, 1980.

A positive correlation was obtained between the number of reflections per unit time and the probable entry of enhanced solar plasma into the magnetosphere and/or local disturbed magnetic conditions. The modes and paths by which the signals propagate are yet to be established. However, regardless of their origin, the echoes seem to be genuine and these observations are therefore unique in the study of LDE radiowave propagation phenomenology.

Background

The phenomenon of Long Delayed Radio Echoes (LDE) has been extensively studied by Hals (1934), Stormer (1929a,b), Budden and Yates (1952), Villard et al. (1969, 1970), Crawford et al. (1970), Sears (1974), Duffett-Smith (1975), Vidmar (1978), Goodacre (1980), and Muldrew (1979). These papers, which reported failure or only limited success in the detection of LDE, contributed to the planning of the experiment and the results described in this letter.

Hals (1934) and Stormer (1929a,b) reported LDE of 3 to 30 seconds, in addition to the usual around-the-world return of 1/7 s, on the transmissions of the Dutch shortwave telegraph station PCJJ in Eindhoven. Budden and Yates (1952) did not detect an LDE in a year of experimentation. Duffett-Smith (1975) also did not detect any LDE in one million transmissions. Villard et al. (1969, 1970) collected and summarized amateur radio LDE reports. Crawford et al. (1970) conducted experiments to test their theory of propagation in an electron plasma mode at very low group velocity. Goodacre (1980) performed E-F layer ducted mode experiments and Muldrew wrote a review of LDE research and proposed a mechanism involving nonlinear wave-wave interactions. Sears' experiment yielded 31 possible LDE in 3700 hours of transmissions over a 5 year period. Vidmar (1978) continued this line of investigation at Sheep Creek, Alaska in 1978 and recorded 9 to 11 possible LDE, but he did not believe any of the recorded events were valid LDE.

Many LDE mechanisms suggested, involve nonclassical propagation modes at, or near, the speed of light, or plasma modes at low group velocites. Nonclassical propagation modes have been dismissed as a possible mechanism by Sears (1974) because the beam dispersion after several seconds would not allow a reflected signal to be detectable above noise. Vidmar (1978) calculated that the low group velocity mechanisms required an order of magnitude more time for generation than is available at HF. The low group velocity ideas have high attenuation per unit time, which requires a secondary amplification scheme for a reflected signal above noise.

Following HF conjugate backscatter experiments at Los Alamos, we proposed an alternative LDE mechanism. This process involves the coupling of HF signals through the ionosphere onto auroral magnetic field lines, whence they propagate along magnetic flux tubes into the outer magnetosphere until total or partial reflection from plasma density fluctuations or magnetic perturbations result in LDE. It was anticipated that these propagation and reflection mechanisms would be effective only during disturbed geomagnetic conditions or following solar flares. The results described may not be dependent upon this mechanism, however it did influence the planning and operation of the experiment.

Experiment

The experimental objectives were to detect LDE, ensure that the LDE were from our transmissions, measure the total time of flight, and determine the Doppler shift of the returning waves. The experiment was conducted during July 8-22, 1980. The radio transmitter was operated from 6 to 12 hours each day, generally from 9 am to 12 pm ADT (1800-0900 UT or 0600-2100 magnetic local time). LDE were observed on 5 days, for 2-3 hours on each occasion. Three periods were around magnetic noon and two periods were in the late magnetic evening hours.

The pre-experiment conditions and expectations were: the transmitter frequency would be above the plasma frequency of the ionosphere; the transmitted radiation would be in the circularly polarized, extraordinary mode in order to be ducted along magnetic field lines in the presence of plasma (Davies 1966); the echoes of such transmitted signals would be received in the circularly polarized, ordinary mode; the transmission and reception would be from the earth's surface in the auroral zone; and radiowave propagation would be at the speed of light.

The Sheep Creek Ionosonde Site of the Geophysical Institute of the University of Alaska, near Fairbanks, was selected for the experiment. The transmitter previously used by Vidmar (1978) was made available to us along with a pair of orthogonal, multiplewire delta antennas (which was shared with the ionosonde). A Collins R390A receiver, a flux-gate magnetometer, test equipment, and engineering support were also supplied by the Institute.

The transmitter power output was 1 kW on 9.9 MHz. The transmitter pulse length was fixed at 10 ms, and any number of pulses could be trans-

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mitted in sequence, with 50 ms between the leading edges of successive pulses.

The R390A receiver i.f. output was demodulated in a d.c.-coupled detector. This signal fed into a signal processor that accepted only those echoes whose length was within a 5- to 15-ms gate and whose intensity exceeded a threshold established by integrating the average detector output for the previous 200 ms. When an echo was accepted by the electronics as valid, the storage oscilloscope trace was intensified and registered the "echo" as a dot on the scope.

The oscilloscope x-axis displayed echoes as a function of time after transmission of a pulse group. The x-axis sweep times used were 2, 10 and 16 s. The Doppler shift was measured by counting the receiver i.f. during the first 5 ms of each pulse return. This measurement was converted to an analog signal and presented as a vertical deflection on the y-axis. The y-axis baseline was moved vertically after each sweep to display up to 18 contiguous 10-s sweeps.

There are three independent methods for ascertaining the character of motions of reflecting regions: (a) change in the echo time of distinctive reflections between successive sweeps; (b) compression or expansion of the 50-ms interpulse spacing; (c) Doppler shift measurements of the individual pulses. Even without knowledge of the signal propagation speed, the relative character of these motions can be noted. Knowledge of the actual propagation speed would permit determination of absolute speeds and displacements of reflecting regions. All Doppler shift-to-velocity conversions in this letter assume radiowave propagation at the speed of light.

Although the storage oscilloscope has virtually no gray scale, when the same location is "hit" a second time the spot size almost doubles. Subsequent "hits" produce little change in spot diameter.

Results

Several thousand apparent LDE, with time delays ranging from 0.5 to 16 s, were detected and recorded on transmissions made from Sheep Creek between 15 and 22 July 1980.

Event 1

Geophysical background. On 14 July 1980, at 0829 UT, Solar Region 2562 produced an X1/1B flare.

LDE recorded. After seven days of operation, on 15 July at 2300 UT, less than an hour from local magnetic noon, the first evidence of possible long delayed echoes was recorded, following several hours of transmissions on that day without LDE. LDE continued to be recorded until 2458 UT, when excessive temperatures forced equipment shutdown. At 2306 UT, 14 LDE were recorded with delays ranging from 7 to 15 s. Figure 1a shows two consecutive transmissions of a two-pulse sequence with a 16-s "listening" period between transmissions. The receiver bandwidth was 16 kHz centered on the transmitted frequency of 9.9 MHz.

The first transmission produced all 14 "hits" in Fig. 1a between 7 and 15 s, plus "hash" at the beginning of the sweep from the transmitted pulses and local backscatter.

The next transmission 16 s later, recorded on the same line, resulted in returns that matched the first eight earlier "hits" so closely, both in time and Doppler shift, that they merged and are seen in Fig. 1a as the brightening and elongating of these dots. The last six hits were intensified only on the first sweep, so they are smaller and less intense.

The information from the first two sweeps was photographed and stored on the oscilloscope; after two min had elapsed, two more transmissions were made to determine if any of the previous targets had moved (Fig. 1b). None of the previous targets were precisely overwritten, but the locations of the previous targets and several new ones in the 4- to 12-s region were hit on both sweeps.

All stored LDE were erased, and 2 min later Fig. 1c was recorded. This consisted of two transmissions, as before, and once more a number of the targets were illuminated on both transmissions, except for the five returns at extreme range that were detected only once. These resemble their probable counterparts in Fig. 1b.

When these data were taken, the system was still being checked out and there was no reason to expect LDE activity (from local magnetic field changes or reported solar flares). However, the character of the radio background noise did change and patterns of illuminated dots started to appear on the storage scope. The overwriting of previously recorded returns was so extraordinary that it was decided to record the data even though these were not regarded as valid LDE at the time.

A search had been made for systematic noise sources within the transmitter and the adjacent ionosonde and all were either eliminated or identified so that they could be recognized as such on the recorded data. Such noise, as for example from the ionosonde's clock, show up as randomly scattered dots at a rate of no more than five in fifteen minutes.

The low rate of such background noise and the fact that the transmissions were not synchronized to either power line or standard time make it extremely improbable that the results shown in Fig. 1 were due to artifacts. In addition to the probability of repeating the timing, it is difficult to conceive of a "noise" process that would also repeat the frequency shift pattern. The evidence indicates that, whatever the process is, some kind of repeatable echo phenomenon was being recorded and that this process was stationary over time periods of at least sixteen seconds.

Event 2

Geophysical background. On 17 July 1980, at 0612 UT, Solar Region 2562 produced an M3/1B parallel ribbon flare in H-alpha. On 18 July at 1930 UT, a proton event reached a maximum of 100 particles/s. The geomagnetic field was quiet until a sudden commencement of activity at 1928 UT. The Sheep Creek magnetometer monitoring the horizontal component of the earth's

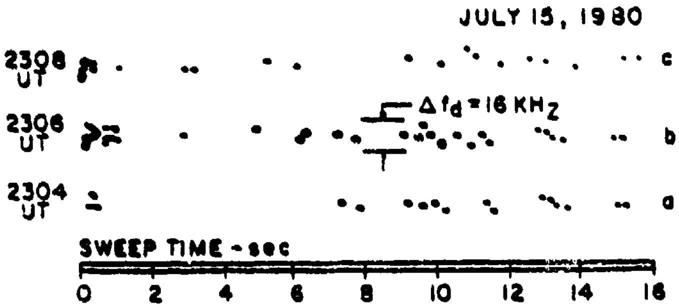

Fig. 1. Composite of three sets of storage scope traces. a is the record of two consecutive sweeps. b consists of the data shown in a, overwritten two minutes later with two more consecutive sweeps. c is two sweeps two minutes later with all prior information erased.

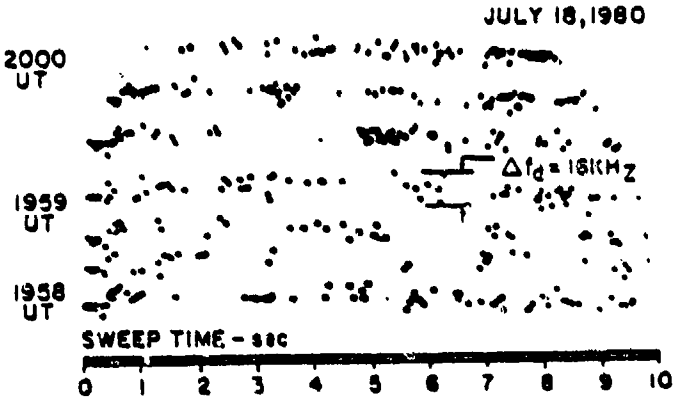

Fig. 3. LDE from a 3-pulse sequence transmitted and received on 9.90 MHz with a receiver i.f. bandwidth of 16 kHz.

magnetic field also dropped by 240 gamma at 1928 UT and remained unsettled for several hours. The ionosonde showed no HF reflections and the College 30-MHz riometer showed increased noise from 1936 to 1956 UT, indicating ionospheric depletion.

LDE recorded. LDE were recorded from 1946 UT until 0126 UT. By 0126 UT the number of returns had decreased significantly and once again temperature considerations forced us to shut down.

Initially, the background noise level was higher than normal on the transmitter frequency and an incoherent pulsed signal was barely audible in the background. On tuning the receiver higher in frequency, the background noise decreased significantly above the 9.908 to 9.912 MHz region and it became apparent that the pulsed signal was LDE from our own transmissions. LDE were still audible, but decreasing rapidly in intensity, at 9.93 MHz. The signal to noise ratio was good at 9.92 MHz, so the data in Fig. 2 was recorded. Since the receiver bandwidth was 16 kHz, all returns on Fig. 2 are from targets with velocities of 182 to 424 km/s toward the earth. Since the returns decreased above 9.93 MHz the maximum target velocities detected were 575 km/s.

A few minutes later the background noise on the transmitter frequency decreased, and the data in Fig. 3 was recorded. The number of LDE per transmission is significantly greater than at higher target speeds. Therefore it seems LDE were apparently reflected from targets with a continuum of speeds ranging from -120 km/s to 575 km/s during this event.

In both Fig. 2 and 3 a triplet of 10-ms pulses, spaced 50-ms center-to-center, were transmitted at the start of each sweep.

Event 3

Geophysical background. On 21 July, Solar Region 2562 produced an M8 x-ray burst with a maximum at 0300 UT. No ionospheric bursts were reported and the radio bursts were unimpressive. On 22 July between 2300 UT and 2316 UT, the Sheep Creek magnetometer indicated a 72-gamma drop in the horizontal component of the terrestrial magnetic field. The ionosonde showed no HF reflections and the riometer saturated for six hours starting about 1946 UT, indicating possible ionospheric depletion or a solar noise storm.

LDE. On 22 July at 2316 UT, following approximately one hour of operation, the 9.9 MHz backscatter went from 0 to over 10 hits per transmission, and the LDE continued at varying rates for several hours. Intense backscatter occurred periodically as shown in Fig. 4. During a particularly active period, the transmit-

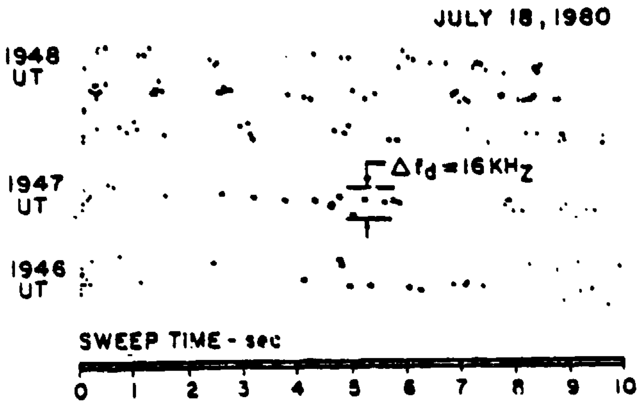

Fig. 2. LDE from 3-pulse sequence transmitted on 9.90 MHz and received on 9.92 MHz with a receiver i.f. bandwidth of 16 kHz.

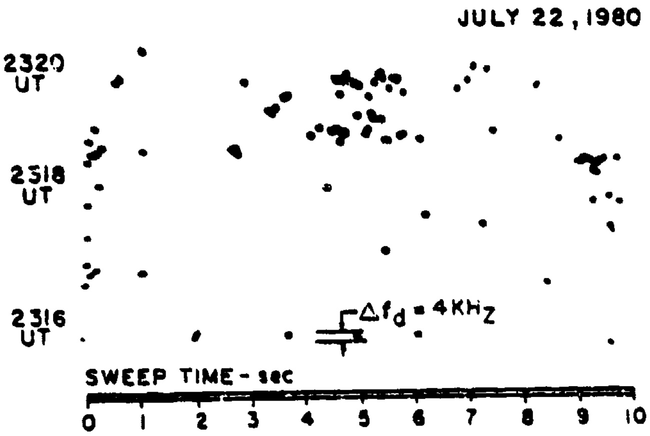

Fig. 4. LDE bursts from a 3-pulse sequence transmitted and received on 9.90 MHz with a receiver i.f. of 4 kHz.

ter was turned off for 16 min to ensure that the returns were from our transmissions. The incoming signals did not drop to zero. Two substantial bursts of rf incoming on 9.9 MHz were recorded about 3 and 6 min after our transmissions ceased, indicating a possible rf radiation source not correlated with our transmissions.

Only a few percent of the data recorded during July are illustrated in this letter; the balance of the experimental data are available in Freyman (1980).

Conclusions

This experiment demonstrated a repeatable technique for the generation and detection of apparent LDE. Several thousand apparent LDE were recorded on film during 5 events that occurred between July 15 and July 22, 1980. During these events LDE were observed for a total of about 12-15 hours and the more interesting 5 hours were documented. The balance of the LDE time was utilized to perform a series of experiments to determine the validity of the returns, propagation modes possible, extent of the Doppler shift of the LDE returns, maximum LDE delay, existence of independent rf bursts and the correlation of LDE with ionosonde, magnetic, and riometer data.

Our data is in agreement with the prior reports of Hals and Stormer. Some transmitted pulses produce no LDE. Other transmitted pulses produce several returns. They reported returns occurring several minutes after transmission. When LDE can be seen, uncorrelated rf bursts also occur every few minutes that have no relationship to the transmitter pulses.

LDE undergo Doppler shifts ranging from zero to 575 km/s as well as possible incoherent and coherent backscatter in the range of 0 to 3 kHz during the early portion of an LDE event.

The x-mode transmissions produced LDE; the o-mode transmissions did not.

LDE were recorded out to 16 s in mid-day, and to comparable times during late evening. The multiple returns from different distances from one transmission may indicate that a multiplicity of transmission ducts are illuminated.

LDE occurred during the probable entry of enhanced solar plasma into the terrestrial system and were most numerous and dynamic when changes in the magnetic field occurred.

The function of this letter is to present the experimental results as we observed, recorded and understand them. Our interpretation of this data will be presented after further analysis.

Acknowledgements. Thanks go to A. R. Koelle for the design of the detector and data processor and also for participation in the Sheep Creek and Platteville experiments. Special thanks also to M. L. Freyman for her participation in the Los Alamos, Platteville, and Sheep Creek experiments. Thanks also to L. M. Duncan, E. W. Hones, Jr., and their colleagues in Los Alamos Scientific Laboratory group P-4 for continued consultation and S. I. Akasofu, R. D. Hunsucker, B. S. Delana, and P. Brooks of the Geophysical Institute of the University of Alaska for consultation and engineering support in the "Arctic."

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